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(54) **Wireless position sensor**

Drahtloser Positionssensor

Capteur de position sans fil

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Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to intrabody tracking systems, and specifically to wireless methods and devices for tracking the position and orientation of an object in the body.

BACKGROUND OF THE INVENTION

[0002] Many surgical, diagnostic, therapeutic and prophylactic medical procedures require the placement of objects such as sensors, treatment units, tubes, catheters, implants and other devices within the body. These procedures cover a large spectrum including, for example:

insertion of electrodes for therapeutic or diagnostic purposes,
placement of tubes to facilitate the infusion of drugs, nutritional and other fluids into a patient's circulatory system or digestive system,
insertion of probes or surgical devices to facilitate cardiac or other types of surgery, and
biopsies or other diagnostic procedures.

[0003] In many instances, insertion of a device is for a limited time, such as during surgery or catheterization. In other cases, devices such as feeding tubes or orthopedic implants are inserted for long-term use. The need exists for providing real-time information for accurately determining the location and orientation of objects within the patient' s body, preferably without using X-ray imaging.

[0004] US Patents 5,391,199 and 5,443,489 to Ben-Haim, describe systems wherein the coordinates of an intrabody probe are determined using one or more field sensors, such as a Hall effect device, coils, or other antennae carried on the probe. Such systems are used for generating three-dimensional location information regarding a medical probe or catheter. Preferably, a sensor coil is placed in the catheter and generates signals in response to externally-applied magnetic fields. The magnetic fields are generated by three radiator coils, fixed to an external reference frame in known, mutually spaced locations. The amplitudes of the signals generated in response to each of the radiator coil fields are detected and used to compute the location of the sensor coil. Each radiator coil is preferably driven by driver circuitry to generate a field at a known frequency, distinct from that of other radiator coils, so that the signals generated by the sensor coil may be separated by frequency into components corresponding to the different radiator coils.

[0005] US Patent 6,198,963 to Ben-Haim et al., describes simplified apparatus for confirmation of intrabody tube location that can be operated by nonprofessionals. The initial location of the object is determined as a reference point, and subsequent measurements are made to determine whether the object has remained in its initial position. Measurements are based upon one or more signals transmitted to and/or from a sensor fixed to the body of the object whose location is being determined. The signal could be ultrasound waves, ultraviolet waves, radio frequency (RF) waves, or static or rotating electromagnetic fields.

[0006] PCT Patent Publication WO 96/05768 to Ben-Haim et al., describes a system that generates six-dimensional position and orientation information regarding the tip of a catheter. This system uses a plurality of sensor coils adjacent to a locatable site in the catheter, for example near its distal end, and a plurality of radiator coils fixed in an external reference frame. These coils generate signals in response to magnetic fields generated by the radiator coils, which signals allow for the computation of six location and orientation coordinates.

[0007] US Patent 6,239,724 to Doron et al., describes a telemetry system for providing spatial positioning information from within a patient's body. The system includes an implantable telemetry unit having (a) a first transducer, for converting a power signal received from outside the body into electrical power for powering the telemetry unit; (b) a second transducer, for receiving a positioning field signal that is received from outside the body; and (c) a third transducer, for transmitting a locating signal to a site outside the body, in response to the positioning field signal.

[0008] US Patent 6,172,499 to Ashe, describes a device for measuring the location and orientation in the six degrees of freedom of a receiving antenna with respect to a transmitting antenna utilizing multiple-frequency AC magnetic signals. The transmitting component consists of two or more transmitting antennae of known location and orientation relative to one another. The transmitting antennae are driven simultaneously by AC excitation, with each antenna occupying one or more unique positions in the frequency spectrum. The receiving antennae measure the transmitted AC magnetic field plus distortions caused by conductive metals. A computer then extracts the distortion component and removes it from the received signals, providing the correct position and orientation output.

[0009] US Patent 4,173,228 to Van Steenwyck et al., describes a catheter locating device based upon inducing a signal in a coil attached to the catheter and monitoring the amplitude and phase of the induced signal.

[0010] US Patents 5,099,845 to Besz et al., and 5,325,873 to Hirschi et al., describe apparatus and methods in which a radiating element is fixed to a medical tube, e.g., a catheter, and the position of the tube is determined responsive to energy radiated from the element.

[0011] US Patent 5,425,382 to Golden, et al., describes apparatus and methods for locating a medical tube in the body of a patient by sensing the static magnetic field strength gradient generated by a magnet fixed to the medical tube.

[0012] US Patents 4,905,698 to Strohl et al. and 5,425,367 to Shapiro, et al., describe apparatus and methods wherein an applied magnetic field induces currents within a coil at the tip of a catheter. Based on these currents, the relative location of the catheter is determined.

[0013] US Patent 5,558,091 to Acker et al., describes a magnetic position and orientation determining system which uses uniform fields from Helmholtz coils positioned on opposite sides of a sensing volume and gradient fields generated by the same coils. By monitoring field components detected at a probe during application of these fields, the position and orientation of the probe is deduced. A representation of the probe is superposed on a separately-acquired image of the subject to show the position and orientation of the probe with respect to the subject.

[0014] US Patent 5,913,820 to Bladen et al., describes apparatus for locating the position of a sensor, preferably in three dimensions, by generating magnetic fields which are detected at the sensor. The magnetic fields are generated from a plurality of locations and enable both the orientation and location of a single coil sensor to be determined.

[0015] Commercial electrophysiological and physical mapping systems based on detecting the position of a probe inside the body are presently available. Among them, CARTO™, developed and marketed by Biosense Webster Inc., Diamond Bar, California is a system for automatic association and mapping of local electrical activity with catheter location.

[0016] An article entitled, "Microtool Opens 3D Window into the Human Body," by Cleopatra Alfenito, Medical Imaging 12(11) (November, 1997), which is incorporated herein by reference, describes the "miniBIRD" device, made by Ascension Technology (Burlington, Vermont). This device "...measures internal organs and their motion by reconstructing the position and orientation of 2D slices to fill a 3D volume... Sensors - as small as 5 mm - can be attached to probes, instruments, or even a fetal head inside the human body. These mini-trackers measure the spatial location of ultrasound probes or other instruments with six degrees of freedom (position and orientation as given by x,y,z, yaw, pitch and roll) in real time. The miniBIRD works by measuring magnetic fields and converting signals to real-time 3D measurements. At the start of each measurement cycle (of which there are up to 144 per second), the system' s triaxial transmitter is driven by a pulsed DC signal. The sensor then measures the transmitted magnetic field pulse. The electronics unit controls the transmitting and receiving elements and converts the received signals into real-time position and orientation measurements, providing for the collection of accurate data This data can then be used for 3D reconstruction of internal images of the heart, blood vessels, stomach, pelvis and other areas as provided by ultrasound or an endoscope."

[0017] Document US 6 239 724 discloses a device according to the preamble of claim 1.

SUMMARY OF THE INVENTION

[0018] It is an object of some aspects of the present invention to provide improved apparatus for real-time determination of the location and orientation of intrabody objects.

[0019] It is a further object of some aspects of the present invention to provide improved position measurement apparatus based on radio frequency signals.

[0020] It is yet a further object of some aspects of the present invention to provide improved apparatus for determining intrabody object location and orientation which can operate in the absence of other locating technologies such as MRI or fluoroscopy.

[0021] It is still a further object of some aspects of the present invention to provide a sensor for intrabody object location that requires neither wiring nor an internal power source.

[0022] It is an additional object of some aspects of the present invention to provide apparatus for intrabody mapping that is light in weight and small in size.

[0023] It is yet an additional object of some aspects of the present invention to provide intrabody mapping apparatus which can readily be integrated into existing mapping support systems.

[0024] In preferred embodiments of the present invention, apparatus for sensing the position and orientation of an object placed within a patient' s body comprises a wireless location transponder containing a power coil, a sensing coil, and a signal processing chip. Typically, the transponder is fixed to a device inserted into the body, such as a catheter or implant. An externally-located driving unit sends a radio frequency (RF) signal, preferably having a frequency in the megahertz range, to drive the power coil in the transponder and thereby power the chip. Additionally, a set of magnetic field generators in fixed locations outside the body produce magnetic fields at different, respective frequencies, typically in the kilohertz range. These fields cause currents to flow in the sensing coil, which depend on the spatial position and orientation of the sensing coil relative to the field generators. The processing chip converts these currents into high-frequency signals, which are transmitted by the power coil to an externally-located signal processing unit. This unit processes the signal in order to determine position and orientation coordinates of the object for display and recording.

[0025] Thus, in contrast to current medical tracking systems, such as the above-mentioned CARTO™ system, the present transponder enables the position and orientation of an object in the body to be determined without the need for any wired connection between the sensing coil and the external processing unit. This sort of wireless operation is particularly advantageous for visualizing the position of implantable devices, which cannot readily be wired to the processing unit. It is also useful in reducing

the number of wires that must be passed through an invasive probe, such as a catheter, in order to operate a position sensor at its distal end. By reducing the number of wires, it is typically possible to reduce the diameter of the probe Furthermore, because the present transponder uses only two coils, with a single coil serving for both power input and signal output, and no internal power source, it can be made substantially smaller than wireless transponders known in the art.

[0026] A clock synchronizer is used to synchronize the signals produced by both the external driving unit and the magnetic field generators. Most preferably, the frequency of the RF driving signal is set to be an integer multiple of the magnetic field frequencies. This clock synchronization enables the transponder chip to use phase-sensitive detection in order to enhance the signal/noise ratio of the signal from the sensor coil. The phase of the sensor signals is preferably also used to resolve ambiguity that would otherwise occur in the signals under 180° reversal of the sensor coil axis.

[0027] Alternatively or additionally, the transponder may comprise multiple sensor coils, preferably three mutually-orthogonal coils, as described in the above-mentioned PCT publication WO 96/05768. In this case, all six position and orientation coordinates can be determined without ambiguity.

[0028] A further advantage of some preferred embodiments of the present invention is that they can be readily integrated into existing electromagnetic catheter-tracking systems, such as the above-mentioned CARTO™ mapping system. In such embodiments, the driving unit and an accompanying receiver, for communicating over the air with the power coil of the wireless transponder, are connected to the processing unit of the tracking system in place of the wires that normally convey position signals from the catheter. The receiver preprocesses the signals that it receives from the power coil, and then passes the signals on to the existing signal processor in the tracking system for position determination and display.

[0029] There is therefore provided, in accordance with a preferred embodiment of the present invention, apparatus for tracking an object, including:

> driver circuits adapted to drive one or more of field generators to generate electromagnetic fields at different, respective frequencies in a vicinity of the object;
> a radio frequency (RF) driver, adapted to radiate a RF driving field toward the object;
> a clock synchronization circuit coupled to the driver circuits and to the RF driver;
> a wireless transponder, fixed to the object, the transponder including:
>
> > at least one sensor coil, coupled so that an electrical current flows in the at least one sensor coil responsive to the electromagnetic fields;
> > a control circuit, coupled to the at least one sensor coil so as to generate an output signal indicative of the current; and
> > a power coil, coupled to receive the RF driving field and to convey electrical energy from the driving field to the control circuit, and further coupled to transmit the output signal generated by the control circuit; and
>
> a signal receiver, adapted to receive the output signal transmitted by the power coil and, responsive thereto, to determine coordinates of the object;

wherein the one or more field generators are adapted to generate the electromagnetic fields at respective field frequencies, and the RF driver is adapted to radiate the RF driving field at a driving frequency, and the one or more field generators and the RF driver are coupled to operate so that the field frequencies and driving frequency are mutually synchronized by the clock synchronization circuit; and

wherein the control circuit is coupled to receive a frequency synchronization signal from the power coil, responsive to the synchronized RF driving field, and to apply the frequency synchronization signal as a frequency reference in generating the output signal.

[0030] Preferably, the electrical current in the at least one sensor coil has frequency components at the different frequencies of the one or more field generators, and the signal generated by the control circuit is indicative of the frequency components of the current.

[0031] Further additionally or alternatively, the control circuit is adapted to generate the output signal so as to indicate a phase of the current flowing in the at least one sensor coil, relative to a phase of the electromagnetic fields.

[0032] Preferably, the control circuit is adapted to generate the output signal responsive to the synchronization of the field frequencies with the driving frequency.

[0033] Further preferably, the driving frequency of the RF driving field is an integer multiple of the field frequencies of the electromagnetic fields of the one or more field generators.

[0034] Even further preferably, the control circuit is further adapted so as to generate an output signal indicative of an amplitude of the current, and the signal receiver is adapted, responsive to the amplitude and phase of the current indicated by the output signal, to determine an orientation of the object.

[0035] In a preferred embodiment, the control circuit includes a voltage-to-frequency (V/F) converter, which is coupled to generate the output signal with an output frequency that varies responsive to the electrical current flowing in the at least one sensor coil.

[0036] In a preferred embodiment, the control circuit comprises a voltage-to-frequency (V/F) converter, coupled to the at least one sensor coil so as to generate an output signal with an output frequency that varies responsive to an amplitude of the electrical current flowing in

the at least one sensor coil.

[0037] In some preferred embodiments, the transponder is adapted to be inserted, together with the object, into a body of a subject, while the one or more field generators and the RF driver are placed outside the body. Preferably, the object includes an elongate probe, for insertion into the body, and the transponder is fixed in the probe so as to enable the receiver to determine the coordinates of a distal end of the probe. Alternatively, the object includes an implant, and the transponder is fixed in the implant so as to enable the receiver to determine the coordinates of the implant within the body. In a preferred embodiment, the implant include a hip joint implant, including a femur head and an acetabulum, and the transponder includes a plurality of transponders fixed respectively to the femur head and the acetabulum, and the signal receiver is adapted to determine a distance between the femur head and the acetabulum responsive to the output signal from the transponders.

[0038] Preferably, the control circuit is adapted to operate powered solely by the electrical energy conveyed thereto by the power coil.

[0039] In a preferred embodiment, the at least one sensor coil includes a single sensor coil, and the signal receiver is adapted, responsive to the indicated phase of the current, to determine a direction of the orientation of the transponder.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings, in which:

Fig. 1 is a schematic, pictorial illustration of a system for tracking the position of a catheter in the heart, in accordance with a preferred embodiment of the present invention;

Fig. 2 is a schematic side view of a catheter, showing details of a wireless location transponder in the catheter, in accordance with a preferred embodiment of the present invention;

Fig. 3 is a block diagram that schematically illustrates elements of driver and processing circuitry used in a wireless position sensing system, in accordance with a preferred embodiment of the present invention; and

Fig. 4 is a schematic, pictorial illustration showing the use of wireless location transponders in a joint implant, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0041] Fig. 1 is a schematic, pictorial illustration of a mapping system 20, for mapping a heart 24 of a subject 26, in accordance with a preferred embodiment of the present invention. System 20 comprises an elongate probe, preferably a catheter 30, which is inserted by a user 22 through a vein or artery of the subject into a chamber of the heart. Catheter 30 comprises a wireless position transponder 40, preferably near the distal tip of the catheter. Transponder 40 is shown in detail in Fig. 2. Optionally, catheter 30 comprises two or more transponders of this sort, mutually spaced along the length of the catheter, in order to give position and orientation coordinates at multiple points along the catheter.

[0042] To operate transponder 40, subject 26 is placed in a magnetic field generated, for example, by situating under the subject a pad containing field generator coils 28 for generating a magnetic field. Coils 28 are driven by driver circuits 32 to generate electromagnetic fields at different, respective frequencies. The generator coils 28 are located external to the subject (patient) 26. A reference electromagnetic sensor (not shown) is preferably fixed relative to the patient, for example, taped to the patient' s back, and catheter 30 containing transponder 40 is advanced into the patient's heart. An additional antenna 54, preferably in the form of a coil, provides RF power to the transponder and receives signals therefrom, as described in detail hereinbelow. Signals received by antenna 54 from transponder 40 in the heart are conveyed to a console 34, which analyzes the signals and then displays the results on a monitor 36. By this method, the precise location of transponder 40 in catheter 30, relative to the reference sensor, can be ascertained and visually displayed. The transponder can also detect displacement of the catheter that is caused by contraction of the heart muscle.

[0043] Some of the features of system 20 are implemented in the above-mentioned CARTO™ system, including the use of the system to generate maps 38 of cardiac electrical and mechanical function. Further aspects of the design of catheter 30 and of system 20 generally are described in the above-mentioned US Patents 5,391,199, 5,443,489 and 6,198,963. The design of transponder 40 and the associated driver and signal processing circuits used in console 34, however, as described hereinbelow, are unique to the present invention.

[0044] Reference is now made to Figs. 2 and 3, which schematically show details of transponder 40 and of driving and processing circuits in console 34, in accordance with a preferred embodiment of the present invention. As shown in Fig. 2, transponder 40 comprises a power coil 42 and a sensing coil 46, coupled to a control chip 44. Coil 42 is preferably optimized to receive and transmit high-frequency signals, in the range above 1 MHz. Coil 46, on the other hand, is preferably designed for operation in the range of 1-3 kHz, the frequencies at which coils 28 generate their electromagnetic fields. Alternatively, other frequency ranges may be used, as dictated by application requirements. The entire transponder 40 is typically 2-5 mm in length and 2-3 mm in outer diameter, enabling it to fit conveniently inside catheter 30.

[0045] As shown in Fig. 3, console 34 comprises a RF power driver 50, which drives antenna 54 to emit a power signal, preferably in the 2-10 MHz range. The power signal causes a current to flow in power coil 42, which is rectified by chip 44 and used to power its internal circuits. Meanwhile, the electromagnetic fields produced by field generator coils 28 cause a current to flow in sensor coil 46. This current has frequency components at the same frequencies as the driving currents flowing through the generator coils. The current components are proportional to the strengths of the components of the respective magnetic fields produced by the generator coils in a direction parallel to the sensor coil axis. Thus, the amplitudes of the currents indicate the position and orientation of coil 46 relative to fixed generator coils 28.

[0046] Chip 44 measures the currents flowing in sensor coil 46 at the different field frequencies. It encodes this measurement in a high-frequency signal, which it then transmits back via power coil 42 to antenna 54. Preferably, chip 44 comprises a voltage-to-frequency (V/F) converter 48, which generates a RF signal whose frequency is proportional to the voltage produced by the sensor coil current flowing across a load. Preferably, the RF signal produced by chip 44 has a carrier frequency in the 50-150 MHz range. The RF signal produced in this manner is modulated with three different frequency modulation (FM) components that vary over time at the respective frequencies of the fields generated by coils 28. The magnitude of the modulation is proportional to the current components at the three frequencies. An advantage of using frequency modulation, rather than amplitude modulation, to convey the sensor coil amplitude measurements from transponder 40 to antenna 54 is that the information in the signal (i.e., the frequency) is unaffected by the variable attenuation of the body tissues through which the signal must pass.

[0047] Alternatively, chip 44 may comprise a sampling circuit and analog/digital (A/D) converter (not shown in the figures), which digitizes the amplitude of the current flowing in sensor coil 46. In this case, chip 44 generates an digitally-modulated signal, and RF-modulates the signal for transmission by power coil 42. Any suitable method of digital encoding and modulation may be used for this purpose. Other methods of signal processing and modulation will be apparent to those skilled in the art.

[0048] The FM or digitally-modulated signal transmitted by power coil 42 is picked up by a receiver 56, coupled to antenna 54. The receiver demodulates the signal to generate a suitable input to signal processing circuits 58 in console 34. Typically, receiver 56 amplifies, filters and digitizes the signals from transponder 40. The digitized signals are received and used by processing circuits 58 to compute the position and orientation of catheter 30. Typically, circuits 58 comprise a general-purpose computer, which is programmed and equipped with appropriate input circuitry for processing the signals from receiver 56. The information derived by circuits 58 is used to generate map 38, for example, or to provide other diagnostic information or guidance to operator 22.

[0049] In an alternative embodiment of the present invention, driver 50, receiver 56 and antenna 54 are retrofitted to an existing tracking system, such as a CARTO™ system. Console 34 in the existing system is designed to receive and process signals received over wires from one or more sensor coils in catheter 30, using existing processing circuits 58 to determine the position and orientation of the catheter. Therefore, in this alternative embodiment, receiver 56 demodulates the signals generated by transponder 40 so as to reconstruct the variable current signals generated by sensor coil 46. The existing processing circuits use this information to determine the catheter position and orientation just as if the sensor coil currents had been received by wired connection.

[0050] Console 34 includes a clock synchronization circuit 52, which is used to synchronize driver circuits 32 and RF power driver 50. Most preferably, the RF power driver operates at a frequency that is an integer multiple of the driving frequencies of field generators 28. Chip 44 can then use the RF signal received by power coil 42 not only as its power source, but also as a frequency reference. Using this reference, chip 44 is able to apply phase-sensitive processing to the current signals generated by sensor coil 46, to detect the sensor coil current in phase with the driving fields generated by coils 28. Receiver 56 can apply phase-sensitive processing methods, as are known in the art, in a similar manner, using the input from clock synchronization circuit 52. Such phase-sensitive detection methods enable transponder 40 to achieve an enhanced signal/noise (S/N) ratio, despite the low amplitude of the current signals in sensor coil 46.

[0051] The single sensor coil 46 shown in Fig. 2 is sufficient, in conjunction with field generator coils 28, to enable processing circuits 58 to generate three dimensions of position and two dimensions of orientation information. The third dimension of orientation (typically rotation of catheter 30 about its longitudinal axis) can be inferred if needed from mechanical information or, when two or more transponders are used in the catheter, from a comparison of their respective coordinates. Alternatively, transponder 40 may comprise multiple sensor coils, preferably three mutually-orthogonal coils, as described, for example, in the above-mentioned PCT publication WO 96/05768. In this case, processing circuits can determine all six position and orientation coordinates of catheter 30 unambiguously.

[0052] Another point of possible ambiguity in determining the orientation coordinates of transponder 40 is that the magnitude of the currents flowing in sensor coil 46 is invariant under reversal of the direction of the axis of the coil. In other words, flipping transponder 40 by 180° through a plane perpendicular to the axis of the sensor coil has no effect on the current amplitude. Under some circumstances, this symmetrical response could cause an error of 180° in determining the coordinates of the transponder.

[0053] While the magnitude of the sensor coil current

is unaffected by flipping the coil axis, the 180° reversal does reverse the phase of the current relative to the phase of the driving electromagnetic fields generated by field generators 28. Clock synchronization circuit 52 can be used to detect this phase reversal and thus overcome the ambiguity of orientation under 180° rotation. Synchronizing the modulation of the RF signal returned by chip 44 to receiver 56 with the currents driving field generators 28 enables receiver 56 to determine the phase of the currents in sensor coil 46 relative to the driving currents. By checking whether the sensor currents are in phase with the driving currents or 180° out of phase, processing circuitry 58 is able to decide in which direction the transponder is pointing.

[0054] Fig. 4 is a schematic, pictorial illustration showing the use of location transponders in an orthopedic procedure, in accordance with a preferred embodiment of the present invention. An advantage of using wireless transponders, such as transponder 40, without an onboard power source, is that the transponders can be inserted in or attached to implantable devices, and then left inside the patient's body for later reference. The embodiment shown in Fig. 4 illustrates hip implant surgery, in which a surgeon is required to position the head of an artificial femur 60 in an artificial acetabulum 62. Typically, before performing the procedure, the surgeon takes X-rays or CT images to visualize the area of the operation, but then must perform the actual surgery without the benefit of real-time three-dimensional visualization.

[0055] In the embodiment shown in Fig. 4, miniature transponders 64 are embedded in femur 60, and further miniature transponders 66 are embedded in the pelvis in the area of acetabulum 62. Transponders 64 and 66 are preferably similar to transponder 40, as shown in Fig. 2. Most preferably, each transponder is configured to transmit signals back to antenna 54 at a different carrier frequency, so that receiver 56 can differentiate between the transponders. At the beginning of surgery, an X-ray image is taken with the head of the femur in proximity to the acetabulum. The image is captured by computer and displayed on a computer monitor. Transponders 64 and 66 are visible in the X-ray image, and their positions in the image are registered with their respective location coordinates, as determined by processing circuitry 58. During the surgery, the movement of the transponders is tracked by circuitry 58, and this movement is used to update the relative positions of the femur and acetabulum in the image on the monitor, using image processing techniques known in the art. The surgeon uses the updated image to achieve proper placement of the femur head in the acetabulum, without the need for repeated X-ray exposures while the surgery is in process.

[0056] After the surgery is finished, the relative positions of transponders 64 and 66 (which remain in the implant) are preferably checked periodically to verify that the proper relation is maintained between the bones. This sort of position monitoring is useful both during recovery and for monitoring the status of the implant over the long term. For example, such monitoring may be used to detect increasing separation of the femur from the acetabulum, which is known in some cases to precede more serious bone deterioration.

[0057] While Figs. 1 and 4 show only two particular applications of wireless position transponders in accordance with preferred embodiments of the present invention, other applications will be apparent to those skilled in the art and are considered to be within the scope of the present invention. For example, and not by way of limitation, such transponders may be fixed to other types of invasive tools, such as endoscopes and feeding tubes, as well as to other implantable devices, such as orthopedic implants used in the knee, the spine and other locations.

[0058] It will thus be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

Claims

1. Apparatus (20) for tracking an object (30), comprising:

    one or more field generators
    driver circuits (32) adapted to drive the one or more field generators (28) to generate electromagnetic fields at different, respective frequencies in a vicinity of the object;
    a radio frequency (RF) driver (50), adapted to radiate a RF driving field toward the object;
    a wireless transponder (40), fixed to the object (30), the transponder comprising:

        at least one sensor coil (46), coupled so that an electrical current flows in the at least one sensor coil responsive to the electromagnetic fields;
        a control circuit (44), coupled to the at least one sensor coil (46) so as to generate an output signal indicative of the current; and
        a power coil (42), coupled to receive the RF driving field and to convey electrical energy from the driving field to the control circuit (44), and further coupled to transmit the output signal generated by the control circuit; and

    a signal receiver (34), adapted to receive the output signal transmitted by the power coil and, responsive thereto, to determine coordinates of

the object (30); **characterized in that** the apparatus comprises a clock synchronization circuit (52) coupled to the driver circuits (32) and to the RF driver (50);

and **in that** the one or more field generators (28) are adapted to generate the electromagnetic fields at respective field frequencies, and the RF driver (50) is adapted to radiate the RF driving field at a driving frequency, and wherein the one or more field generators (28) and the RF driver (50) are coupled to operate so that the field frequencies and the driving frequency are mutually synchronized by the clock synchronization circuit (52); and
and **in that** the control circuit (44) is coupled to receive a frequency synchronization signal from the power coil (42), responsive to the synchronized RF driving field, and to apply the frequency synchronization signal as a frequency reference in generating the output signal.

2. Apparatus according to claim 1, wherein the electrical current in the at least one sensor coil (46) has frequency components at the different frequencies of the one or more field generators (28), and wherein the signal generated by the control circuit (44) is indicative of the frequency components of the current.

3. Apparatus according to claim 1, wherein the control circuit (44) is adapted to generate the output signal so as to indicate a phase of the current flowing in the at least one sensor coil (46), relative to a phase of the electromagnetic fields.

4. Apparatus according to claim 3, wherein the control circuit (44) is adapted to generate the output signal responsive to the synchronization of the field frequencies with the driving frequency.

5. Apparatus according to any preceding claim, wherein the driving frequency of the RF driving field is an integer multiple of the field frequencies of the electromagnetic fields of the one or more field generators (28).

6. Apparatus according to claim 3, wherein the control circuit (44), is further adapted so as to generate an output signal indicative of an amplitude of the current, and wherein the signal receiver (34) is adapted, responsive to the amplitude and phase of the current indicated by the output signal, to determine an orientation of the object (30).

7. Apparatus according to claim 6, wherein the at least one sensor coil comprises a single sensor coil (46), and wherein the signal receiver is adapted, responsive to the indicated phase of the current, to determine a direction of the orientation of the transponder (40).

8. Apparatus according to claim 1 or claim 6, wherein the control circuit (44) comprises a voltage-to-frequency (V/F) converter (48), which is coupled to generate the output signal with an output frequency that varies responsive to the electrical current flowing in the at least one sensor coil (46).

9. Apparatus according to claim 1, wherein the control circuit (44) comprises a voltage-to-frequency (V/F) converter (48), coupled to the at least one sensor coil (46) so as to generate an output signal with an output frequency that varies responsive to an amplitude of the electrical current flowing in the at least one sensor coil.

10. Apparatus according to claim 1,6 or 9, wherein the transponder (40) is adapted to be inserted, together with the object (30), into a body of a subject (26), while the one or more field generators (28) and the RF driver (50) are placed outside the body.

11. Apparatus according to claim 10, wherein the object comprises an elongate probe (30), for insertion into the body, and wherein the transponder (40) is fixed in the probe (30) so as to enable the receiver (34) to determine the coordinates of a distal end of the probe.

12. Apparatus according to claim 10, wherein the object comprises an implant, and wherein the transponder (40) is fixed in the implant so as to enable the receiver to determine the coordinates of the implant within the body.

13. Apparatus according to claim 12, wherein the implant comprises a hip joint implant, comprising a femur head (60) and an acetabulum (62), and wherein the transponder comprises a plurality of transponders (64, 66) fixed respectively to the femur head and the acetabulum, and wherein the signal receiver is adapted to determine a distance between the femur head (60) and the acetabulum (62) responsive to the output signal from the transponders (64, 66).

14. Apparatus according to claim 1, wherein the control circuit (44) is adapted to operate powered solely by the electrical energy conveyed thereto by the power coil (42).

Patentansprüche

1. Vorrichtung (20) zum Verfolgen eines Objekts (30), die folgendes umfaßt:

einen oder mehrere Feldgeneratoren,

Treiberschaltungen (32), die geeignet sind, den einen oder die mehreren Feldgeneratoren (28) zu treiben, um elektromagnetische Felder mit unterschiedlichen jeweiligen Frequenzen in der Nähe des Objekts zu erzeugen;
einen Hochfrequenz-Treiber (HF-Treiber) (50), der geeignet ist, ein HF-Treibfeld in Richtung auf das Objekt auszusenden;
einen drahtlosen Transponder (40), der an dem Objekt (30) befestigt ist, wobei der Transponder folgendes umfaßt:

mindestens eine Sensorspule (46), die so gekoppelt ist, daß in Antwort auf die elektromagnetischen Felder ein elektrischer Strom in der mindestens einen Sensorspule fließt;
eine Steuerschaltung (44), die mit der mindestens einen Sensorspule (46) so gekoppelt ist, daß sie ein Ausgangssignal erzeugt, welches indikativ für den Strom ist; und
eine Leistungsspule (42), die gekoppelt ist, um das HF-Treibfeld zu empfangen und elektrische Energie von dem Treibfeld zur Steuerschaltung (44) zu liefern, und die ferner gekoppelt ist, um das von der Steuerschaltung erzeugte Ausgangssignal zu übertragen; und
einen Signalempfänger (34), der geeignet ist, das von der Leistungsspule übertragene Ausgangssignal zu empfangen und in Antwort darauf die Koordinaten des Objekts (30) zu ermitteln; **dadurch gekennzeichnet, daß**
die Vorrichtung eine Takt-Synchronisationsschaltung (52) umfaßt, die mit den Treiberschaltungen (32) und dem HF-Treiber (50) gekoppelt ist, und daß der eine oder die mehreren Feldgeneratoren (28) geeignet sind, die elektromagnetischen Felder bei jeweiligen Feldfrequenzen zu erzeugen, und der HF-Treiber (50) geeignet ist, das HF-Treibfeld bei einer Treibfrequenz auszusenden, und wobei der eine oder die mehreren Feldgeneratoren (28) und der HF-Treiber (50) gekoppelt sind, um so zu arbeiten, daß die Feldfrequenzen und die Treibfrequenz durch die Takt-Synchronisationsschaltung (52) miteinander synchronisiert sind;
und daß die Steuerschaltung (44) gekoppelt ist, um ein Frequenz-Synchronisationssignal in Antwort auf das synchronisierte HF-Treibfeld von der Leistungsspule (42) zu empfangen, und um das Frequenz-Synchronisationssignal als Frequenzreferenz beim Erzeugen des Ausgangssignals zu verwenden.

2. Vorrichtung nach Anspruch 1, bei der der elektrische Strom in der mindestens einen Sensorspule (46) Frequenzkomponenten bei den unterschiedlichen Frequenzen des einen oder der mehreren Feldgeneratoren (28) aufweist, und bei der das von der Steuerschaltung (44) erzeugt Signal indikativ für die Frequenzkomponenten des Stroms ist.

3. Vorrichtung nach Anspruch 1, bei der die Steuerschaltung (44) geeignet ist, das Ausgangssignal so zu erzeugen, daß es eine Phase des Stroms, welcher in der mindestens einen Sensorspule (46) fließt, relativ zu einer Phase der elektromagnetischen Felder anzeigt.

4. Vorrichtung nach Anspruch 3, bei der die Steuerschaltung (44) geeignet ist, das Ausgangssignal in Antwort auf die Synchronisation der Feldfrequenzen mit der Treibfrequenz zu erzeugen.

5. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der die Treibfrequenz des HF-Treibfeldes ein ganzzahliges Vielfaches der Feldfrequenzen der elektromagnetischen Felder des einen oder der mehreren Feldgeneratoren (28) ist.

6. Vorrichtung nach Anspruch 3, bei der die Steuerschaltung (44) ferner geeignet ist, ein Ausgangssignal zu erzeugen, welches indikativ für eine Amplitude des Stroms ist, und wobei der Signalempfänger (34) geeignet ist, in Antwort auf die Amplitude und die Phase des Stroms, welche durch das Ausgangssignal angezeigt werden, eine Orientierung des Objekts (30) zu ermitteln.

7. Vorrichtung nach Anspruch 6, bei der die mindestens eine Sensorspule eine einzige Sensorspule (46) umfaßt, und bei der der Signalempfänger geeignet ist, in Antwort auf die angezeigte Phase des Stroms, eine Richtung der Orientierung des Transponders (40) zu ermitteln.

8. Vorrichtung nach Anspruch 1 oder Anspruch 6, bei der die Steuerschaltung (44) einen Spannungs-/Frequenz-Wandler (V/F-Wandler) (48) umfaßt, der gekoppelt ist, um das Ausgangssignal mit einer Ausgangsfrequenz zu erzeugen, die in Antwort auf den elektrischen Strom, welcher in der mindestens einen Sensorspule (46) fließt, variiert.

9. Vorrichtung nach Anspruch 1, bei der die Steuerschaltung (44) einen Spannungs-/Frequenz-Wandler (V/F-Wandler) (48) umfaßt, der mit der mindestens einen Sensorspule (46) gekoppelt ist, um ein Ausgangssignal mit einer Ausgangsfrequenz zu erzeugen, die in Antwort auf eine Amplitude des elektrischen Stroms, welcher in der mindestens einen Sensorspule fließt, variiert.

10. Vorrichtung nach Anspruch 1, 6 oder 9, bei der der Transponder (40) geeignet ist, zusammen mit dem Objekt (30) in einen Körper eines Subjekts (26) eingeführt zu werden, während der eine oder die mehreren Feldgeneratoren (28) und der HF-Treiber (50) außerhalb des Körpers angeordnet sind.

11. Vorrichtung nach Anspruch 10, bei der das Objekt eine längliche Sonde (30) zum Einführen in den Körper umfaßt, und bei der der Transponder (40) in der Probe (30) so befestigt ist, daß der Empfänger (34) in der Lage ist, die Koordinaten eines distalen Endes der Sonde zu ermitteln.

12. Vorrichtung nach Anspruch 10, bei der das Objekt ein Implantat umfaßt, und bei der der Transponder (40) in dem Implantat so befestigt ist, daß der Empfänger in der Lage ist, die Koordinaten des Implantats innerhalb des Körpers zu ermitteln.

13. Vorrichtung nach Anspruch 12, bei der das Implantat ein Hüftgelenksimplantat umfaßt, umfassend einen Femur-Kopf (60) und ein Acetabulum (62), und wobei der Transponder eine Mehrzahl von Transpondern (64, 66) umfaßt, die an dem Femur-Kopf bzw. dem Acetabulum befestigt sind, und wobei der Signalempfänger geeignet ist, einen Abstand zwischen dem Femur-Kopf (60) und dem Acetabulum (62) in Antwort auf das Ausgangssignal von den Transpondern (64, 66) zu ermitteln.

14. Vorrichtung nach Anspruch 1, bei der die Steuerschaltung (44) geeignet ist, nur mit der elektrischen Energie zu arbeiten, die ihr durch die Leistungsspule (42) zugeführt wird.

Revendications

1. Appareil (20) pour suivre un objet (30), comprenant :

un ou plusieurs générateurs de champ,
des circuits d'attaque (32) adaptés pour entraîner le ou les générateurs de champ (28) pour générer des champs électromagnétiques à des fréquences respectives différentes au voisinage de l'objet ;
une unité de commande (50) radiofréquence (RF), adaptée pour émettre un champ de commande RF vers l'objet ;
un transpondeur sans fil (40), fixé à l'objet (30), le transpondeur comprenant :

au moins une bobine de capteur (46), couplée de sorte qu'un courant électrique circule dans au moins une bobine de capteur réactive aux champs électromagnétiques ;
un circuit de commande (44), couplé à la au moins une bobine de capteur (46) de façon à générer un signal de sortie indiquant le courant ; et
une bobine d'induction (42), couplée pour recevoir le champ de commande RF et pour acheminer l'énergie électrique du champ de commande au circuit de commande (44), et en outre couplée pour transmettre le signal de sortie généré par le circuit de commande ; et
un récepteur de signal (34), adapté pour recevoir le signal de sortie transmis par la bobine d'induction et, réactif à celle-ci pour déterminer les coordonnées de l'objet (30) ;
caractérisé en ce que l'appareil comprend un circuit de synchronisation d'horloge (52) couplé aux circuits d'attaque (32) et à l'unité de commande RF (50) ;
et **en ce que** le ou les générateurs de champ (28) sont adaptés pour générer les champs électromagnétiques à des fréquences de champ respectives, et l'unité de commande RF (50) est adaptée pour émettre un champ de commande RF à une fréquence de commande, et dans lequel le ou les générateurs de champ (28) et l'unité de commande RF (50) sont couplés pour fonctionner de sorte que les fréquences de champ et la fréquence de commande soient mutuellement synchronisées par le circuit de synchronisation d'horloge (52); et
en ce que le circuit de commande (44) est couplé pour recevoir un signal de synchronisation de fréquence de la bobine d'induction (42), réactif au champ de commande RF synchronisé, et pour appliquer le signal de synchronisation de fréquence en tant que fréquence de référence dans la génération du signal de sortie.

2. Appareil selon la revendication 1, dans lequel le courant électrique dans la au moins une bobine de capteur (46) comporte des composantes de fréquence aux fréquences différentes d'un ou plusieurs générateurs de champ (28), et dans lequel le signal généré par le circuit de commande (44) indique les composantes de fréquence du courant.

3. Appareil selon la revendication 1, dans lequel le circuit de commande (44) est adapté pour générer le signal de sortie de façon à indiquer une phase du courant circulant dans la au moins une bobine de capteur (46), par rapport à une phase des champs électromagnétiques.

4. Appareil selon la revendication 3, dans lequel le circuit de commande (44) est adapté pour générer le signal de sortie en réaction à la synchronisation des

fréquences de champ avec la fréquence de commande.

5. Appareil selon l'une quelconque des revendications précédentes, dans lequel la fréquence de commande du champ de commande RF est un entier multiple des fréquences de champ des champs électromagnétiques du ou des générateurs de champ (28).

6. Appareil selon la revendication 3, dans lequel le circuit de commande (44) est en outre adapté de façon à générer un signal de sortie indiquant une amplitude du courant, et dans lequel le récepteur de signal (34) est adapté, en réaction à l'amplitude et à la phase du courant indiqué par le signal de sortie, pour déterminer une orientation de l'objet (30).

7. Appareil selon la revendication 6, dans lequel la au moins une bobine de capteur comprend une bobine de capteur (46) unique, et dans lequel le récepteur de signal est adapté, en réaction à la phase du courant indiquée, pour déterminer une direction de l'orientation du transpondeur (40).

8. Appareil selon la revendication 1 ou la revendication 6, dans lequel le circuit de commande (44) comprend un convertisseur (48) tension-fréquence (V/F), qui est couplé pour générer le signal de sortie avec une fréquence de sortie qui varie en réaction au courant électrique circulant dans la au moins une bobine de capteur (46).

9. Appareil selon la revendication 1, dans lequel le circuit de commande (44) comprend un convertisseur (48) tension-fréquence (V/F), couplé à la au moins une bobine de capteur (46) de façon à générer un signal de sortie avec une fréquence de sortie qui varie en réaction à une amplitude du courant électrique circulant dans la au moins une bobine de capteur.

10. Appareil selon la revendication 1, 6 ou 9, dans lequel le transpondeur (40) est adapté pour être inséré, avec l'objet (30), dans le corps d'un sujet (26), tandis que le ou les générateurs de champ (28) et l'unité de commande RF (50) sont placés à l'extérieur du corps.

11. Appareil selon la revendication 10, dans lequel l'objet comprend une sonde allongée (30), pour une insertion dans le corps, et dans lequel le transpondeur (40) est fixé dans la sonde (30) de manière à permettre au récepteur (34) de déterminer les coordonnées d'une extrémité distale de la sonde.

12. Appareil selon la revendication 10, dans lequel l'objet comprend un implant, et dans lequel le transpondeur (40) est fixé dans l'implant de façon à permettre au récepteur de déterminer les coordonnées de l'implant dans le corps.

13. Appareil selon la revendication 12, dans lequel l'implant comprend un implant pour l'articulation de la hanche, comprenant une tête de fémur (60) et un acétabulum (62), et dans lequel le transpondeur comprend une pluralité de transpondeurs (64, 66) fixés respectivement à la tête du fémur et à l'acétabulum, et dans lequel le récepteur de signal est adapté pour déterminer une distance entre la tête du fémur (60) et l'acétabulum (62) en réaction au signal de sortie provenant des transpondeurs (64, 66).

14. Appareil selon la revendication 1, dans lequel le circuit de commande (44) est adapté pour fonctionner en étant alimenté uniquement par l'énergie électrique acheminée jusqu'à lui par la bobine d'induction (42).

FIG. 1

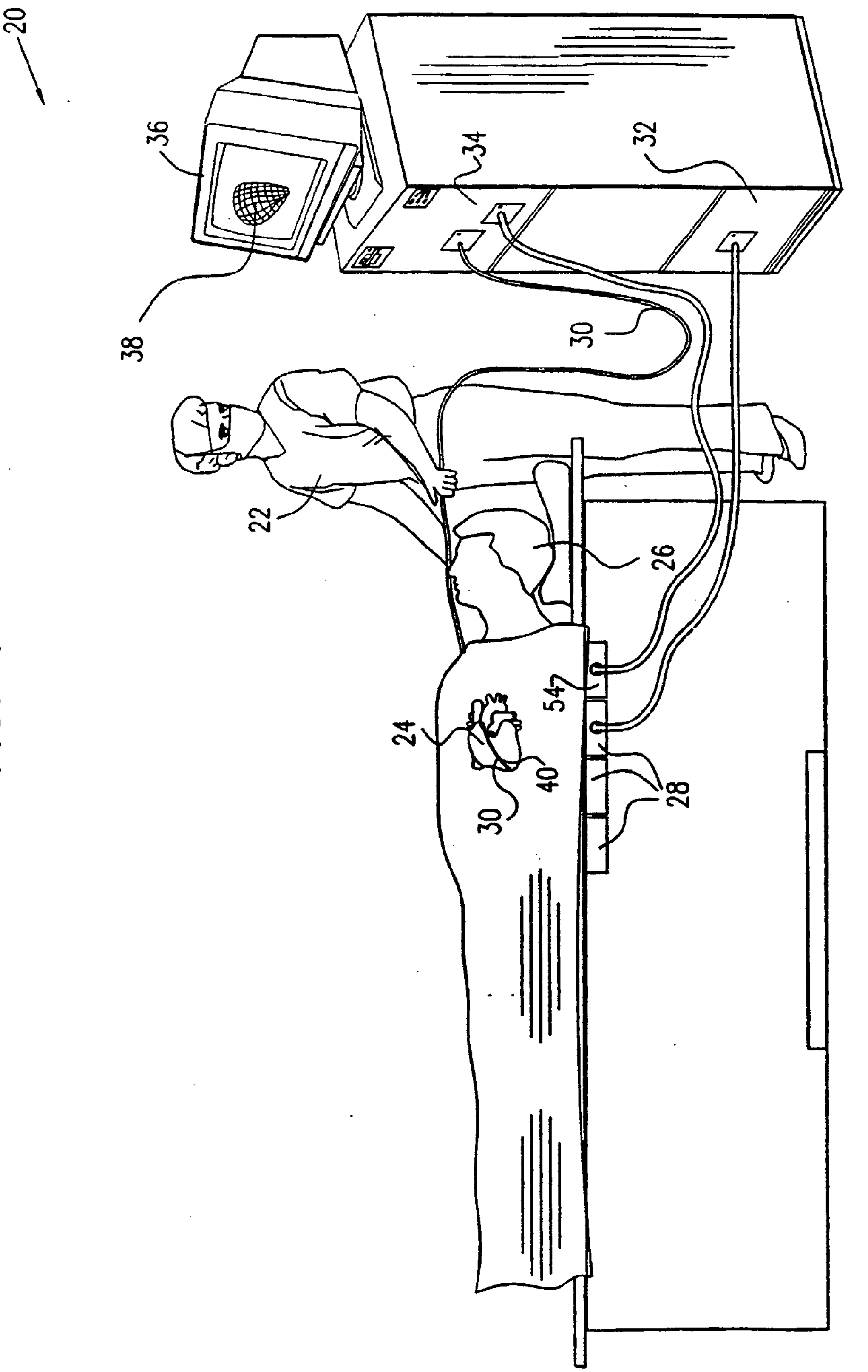


FIG. 2

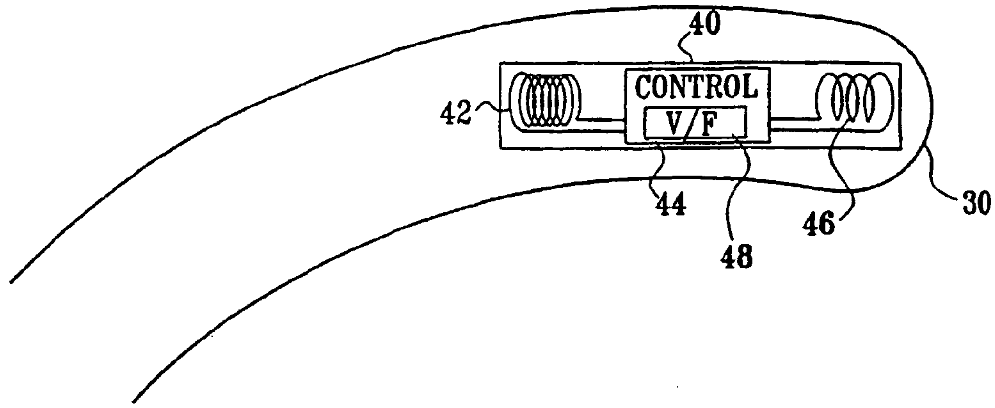
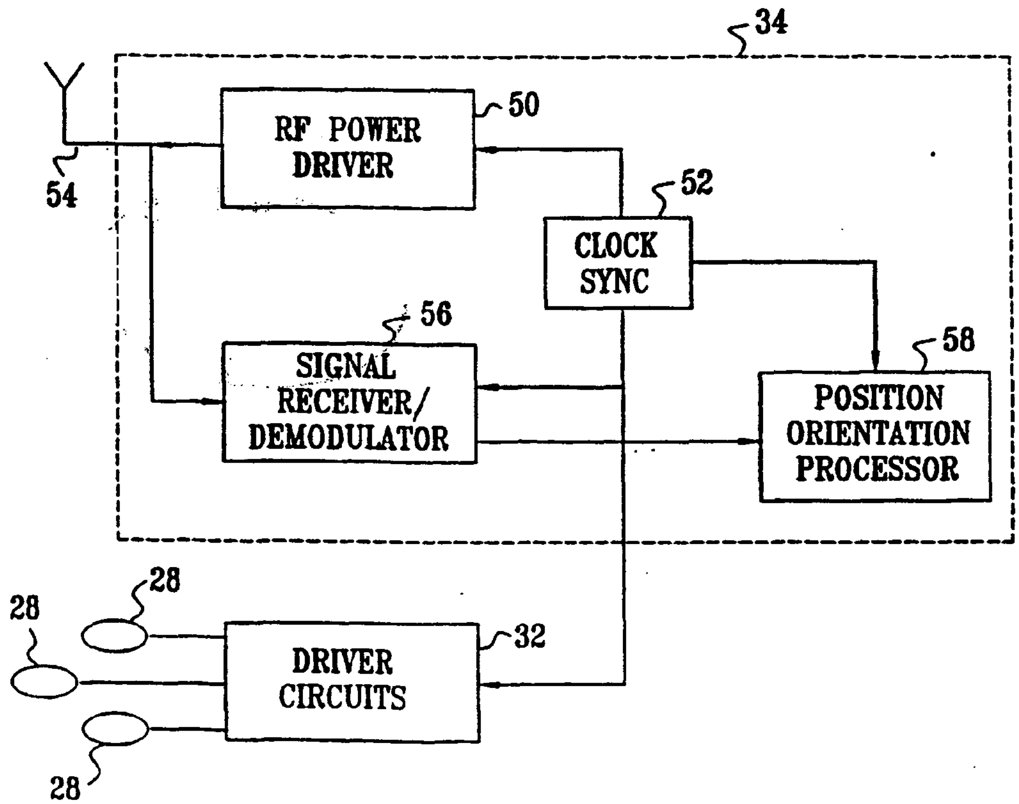

40
CONTROL
V/F
42
44
48
46
30

FIG. 3


34
RF POWER
DRIVER
50
54
52
CLOCK
SYNC
56
SIGNAL
RECEIVER/
DEMODULATOR
58
POSITION
ORIENTATION
PROCESSOR
28
28
DRIVER
CIRCUITS
32
28

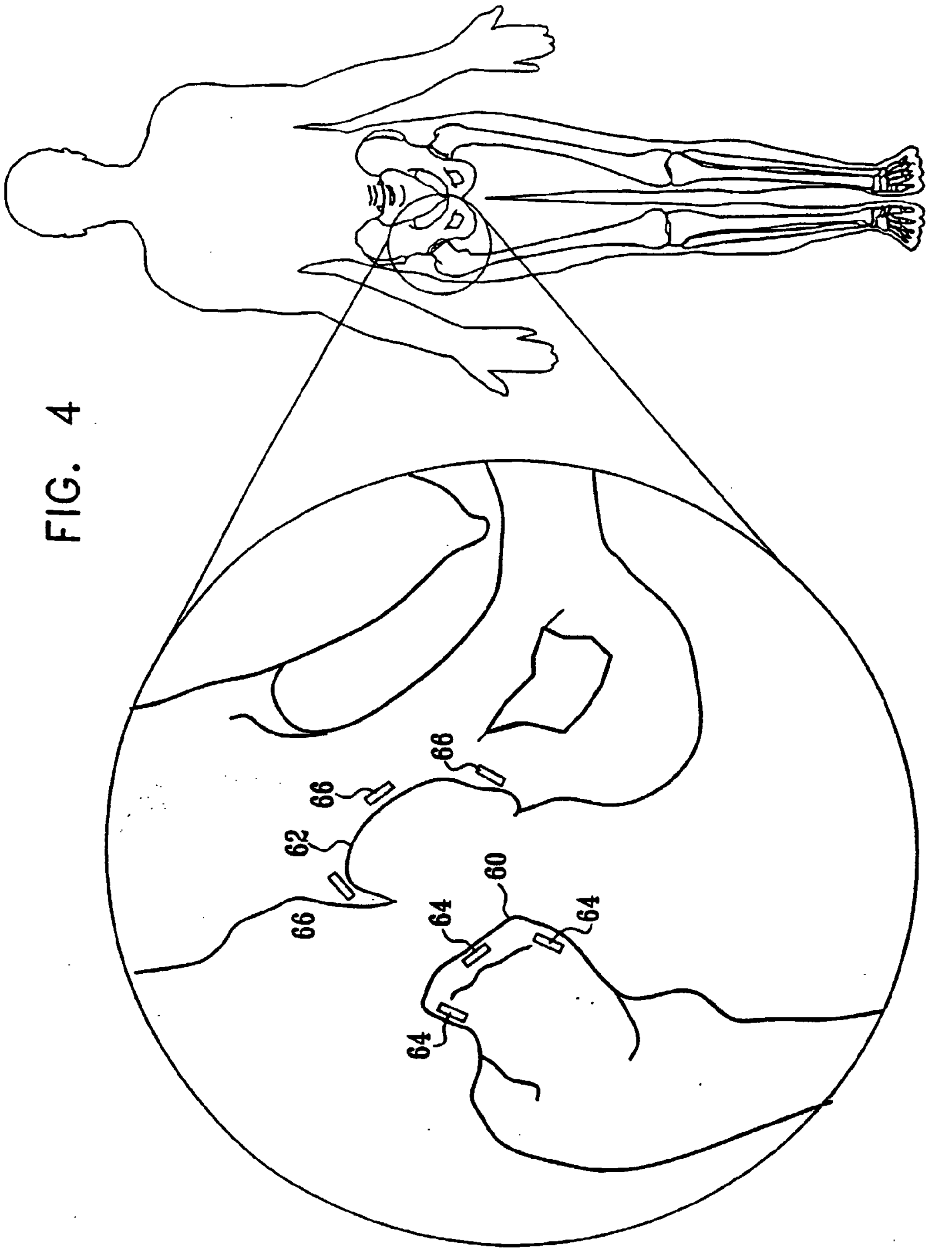


FIG. 4

REFERENCES CITED IN THE DESCRIPTION

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